Synchronized motion in 2D complex plasma crystals

Introduction

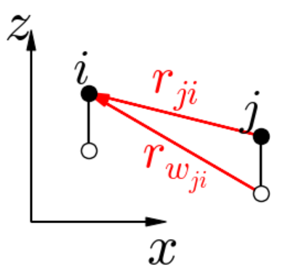
- Mode-coupling Instability (MCI)
- Molecular dynamics Simulations

Results

- Asymmetric triggering of MCI
- Synchronized motion

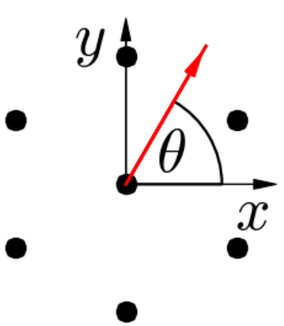
Conclusion

Model of 2D crystal



$$m\ddot{\mathbf{r}}_i + m\nu\dot{\mathbf{r}}_i = \sum_{j\neq i} \mathbf{F}_{ji} + \mathbf{C}_i$$

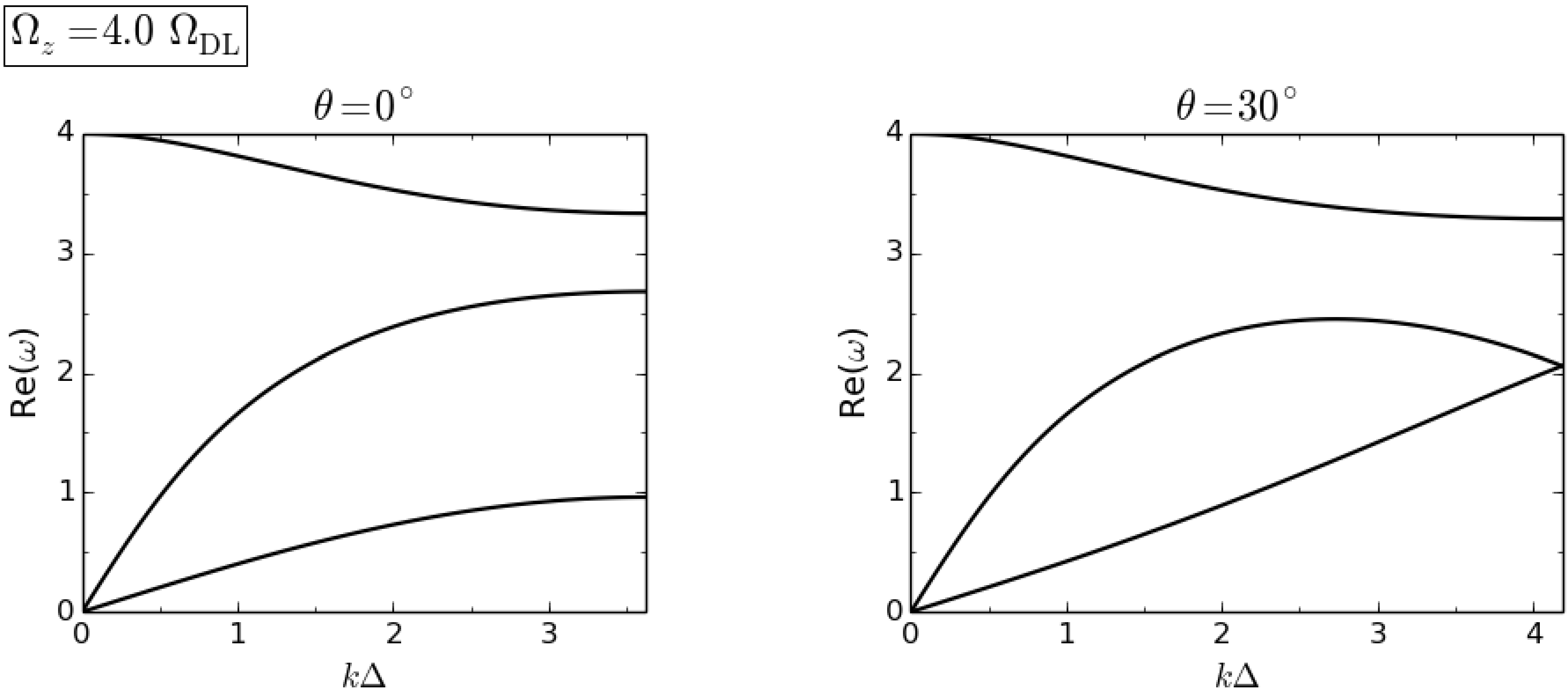
$$\mathbf{F}_{ji} = \frac{Q^2}{r_{ji}^2} \exp\left(-\frac{r_{ji}}{\lambda}\right)\left(1+\frac{r_{ji}}{\lambda}\right)\frac{\mathbf{r}_{ji}}{r_{ji}} - \frac{q|Q|}{r_{w_{ji}}^2} \exp\left(-\frac{r_{w_{ji}}}{\lambda}\right)\left(1+\frac{r_{w_{ji}}}{\lambda}\right)\frac{\mathbf{r}_{w_{ji}}}{r_{w_{ji}}}$$



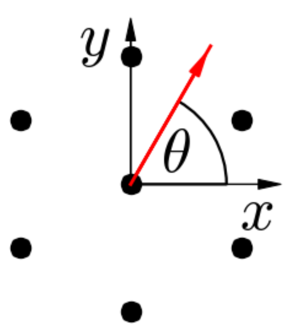
$$\mathbf{C}_i = -\begin{pmatrix} 0 \\ 0 \\ \Omega_z^2 z_i \end{pmatrix}$$

DLR

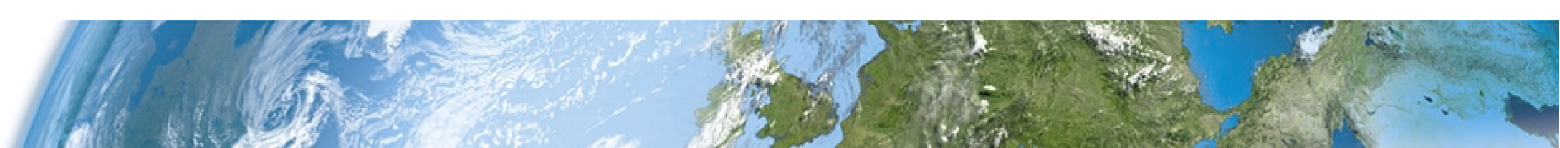
Dispersion Relation



Zhdanov *et al*, Phys. Plasmas (2009)

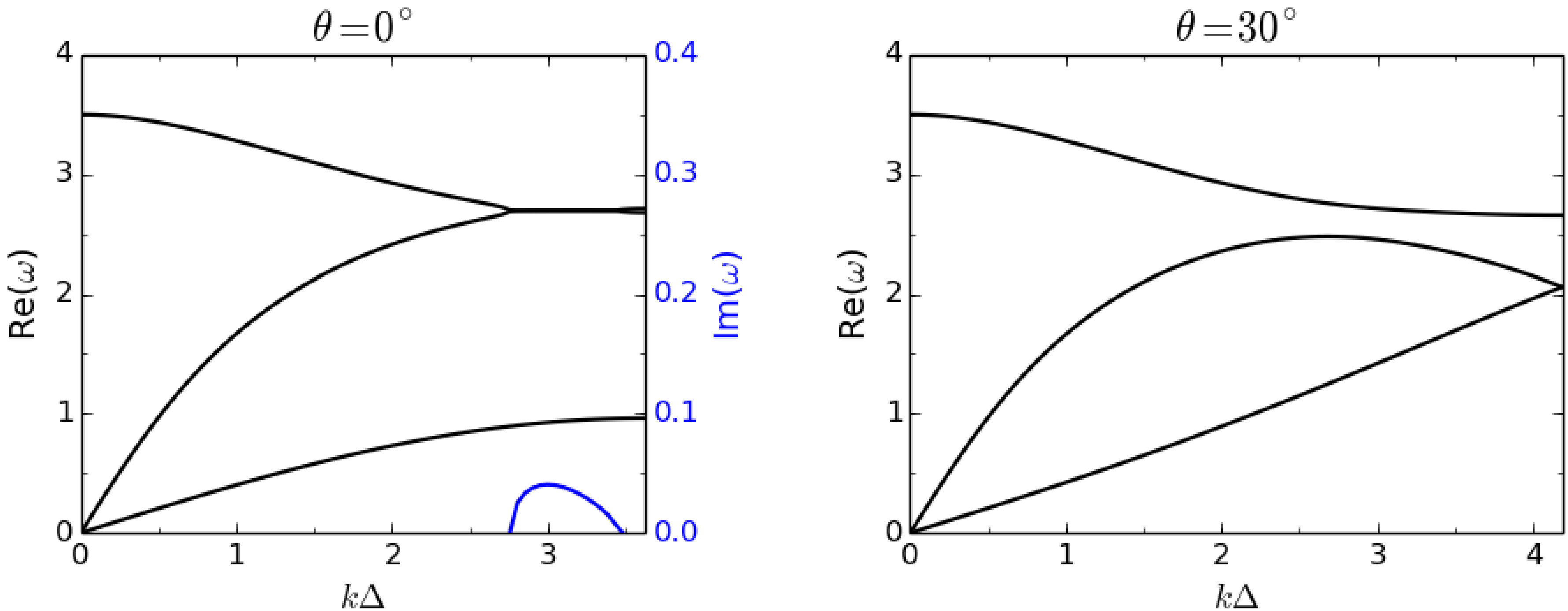


DLR



Dispersion Relation

$\boxed{\Omega_z = 3.5\ \Omega_{\mathrm{DL}}}$



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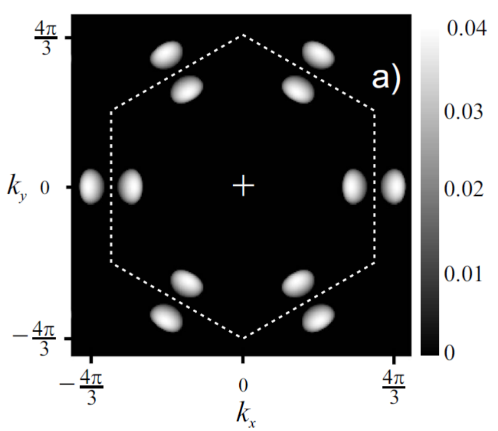
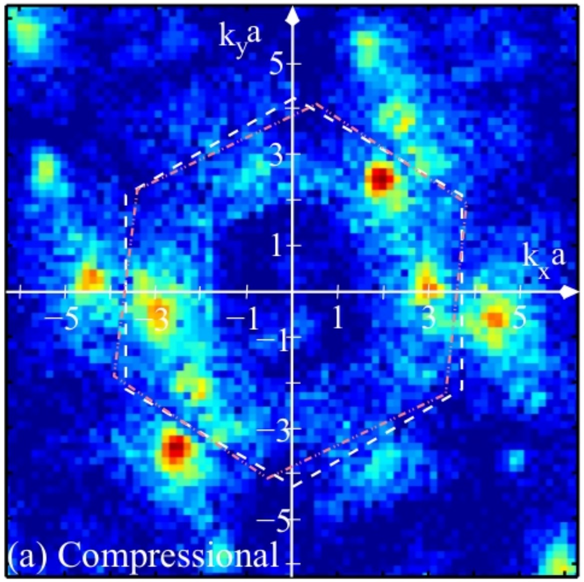
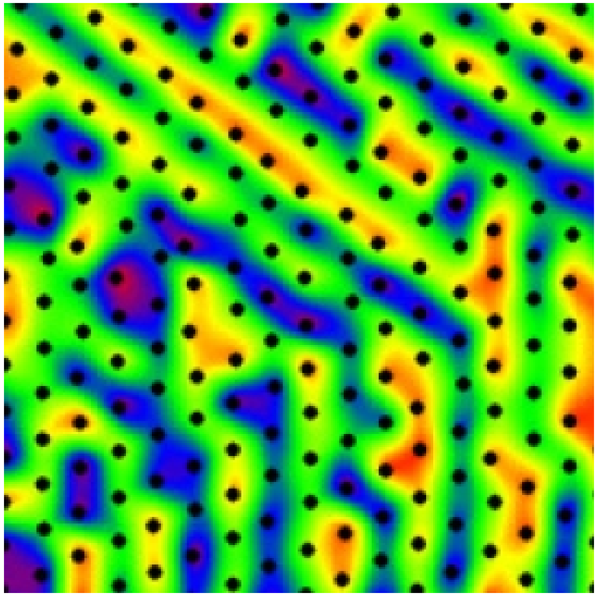


Asymmetric Triggering of MCI





Couëdel *et al*, PRE (2014)

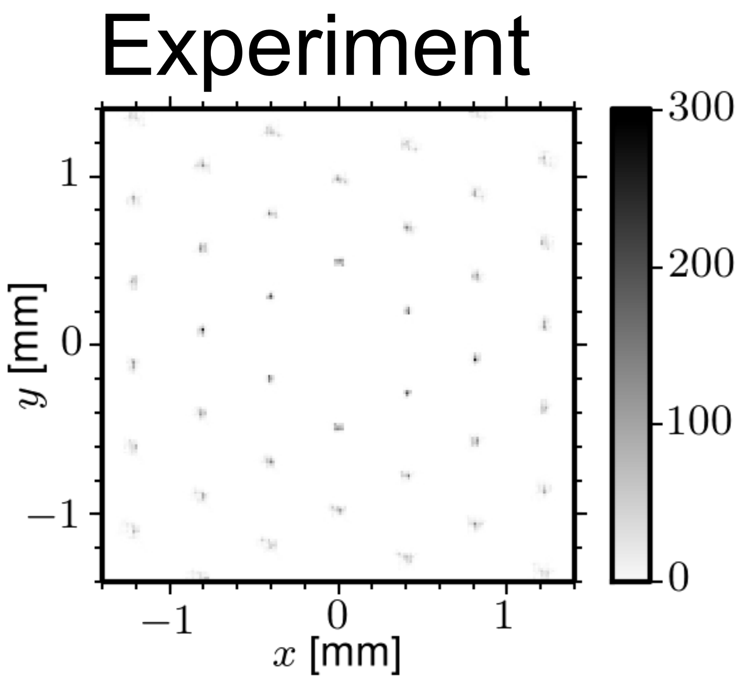
md Simulation

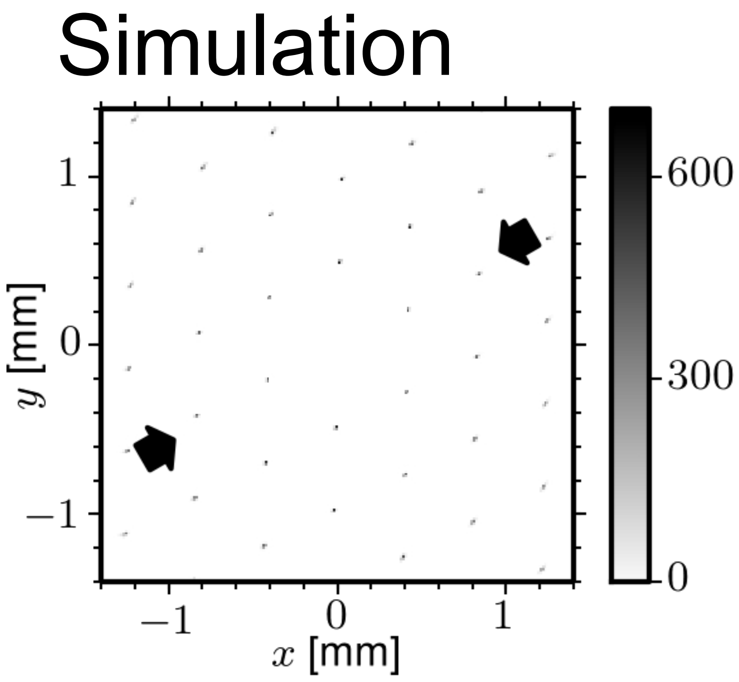
$$m\ddot{\mathbf{r}}_i + m\nu\dot{\mathbf{r}}_i = \sum_{j\neq i}\mathbf{F}_{ji} + \mathbf{C}_i + \mathbf{L}_i$$

$$\mathbf{C}_i = -\begin{pmatrix} \Omega_s^2 x_i + \Omega_a^2(x_i\cos 2\alpha + y_i \sin 2\alpha) \\ \Omega_s^2 y_i + \Omega_a^2(x_i \sin 2\alpha - y_i\cos 2\alpha) \\ \Omega_z^2 z_i \end{pmatrix}$$

$$\langle \mathbf{L}_i(t)\rangle = 0\,, \quad \langle \mathbf{L}_i(t+\tau)\mathbf{L}_j(t)\rangle = 2\nu m T\delta_{ij}\delta(\tau)$$

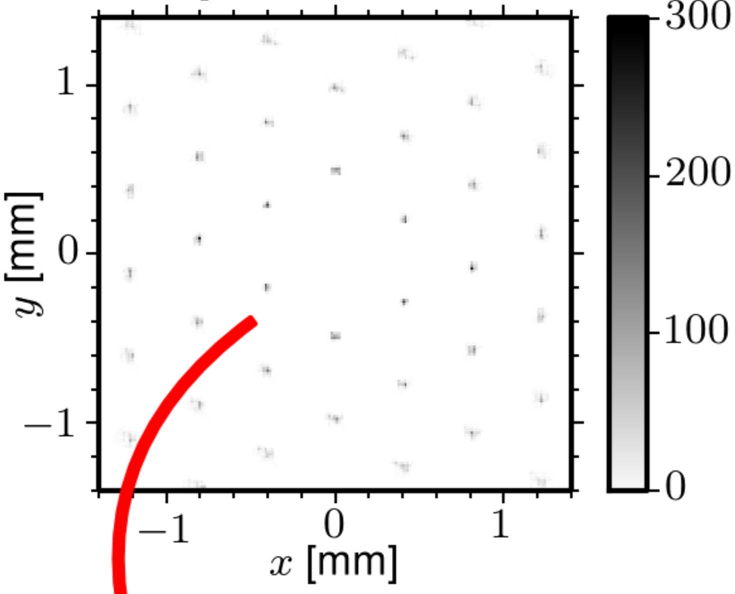
Pair Correlation

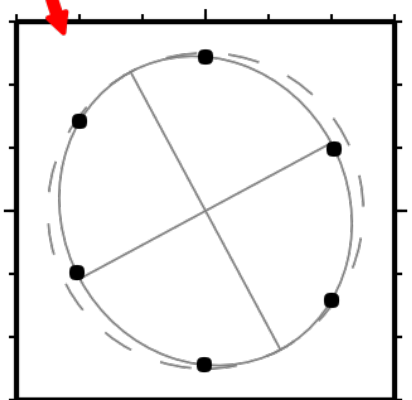




Pair Correlation

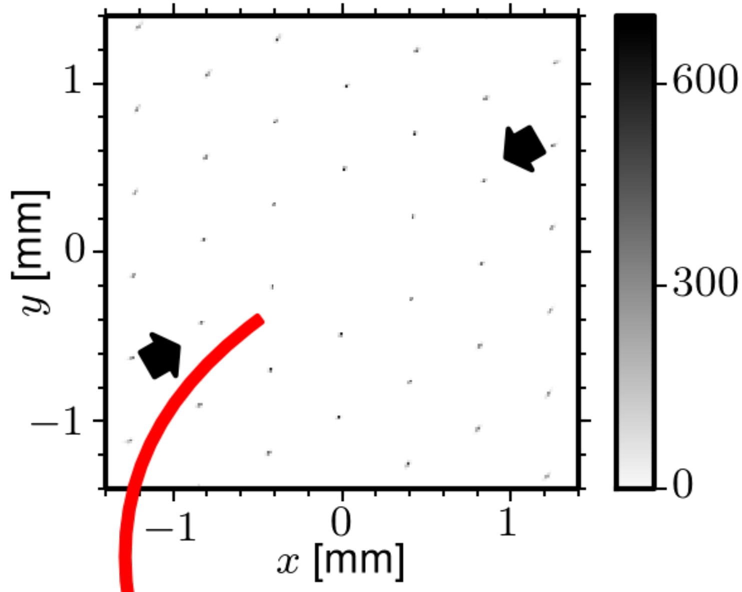
Experiment

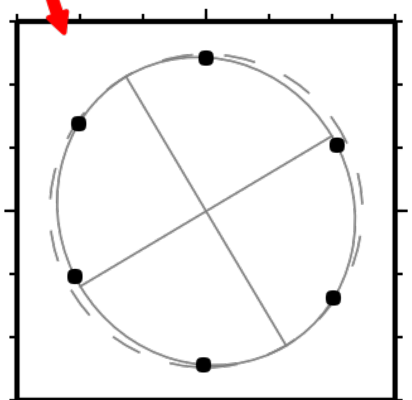




$\beta = 27 \pm 2.00$
$\epsilon = 0.42 \pm 0.07$

Simulation

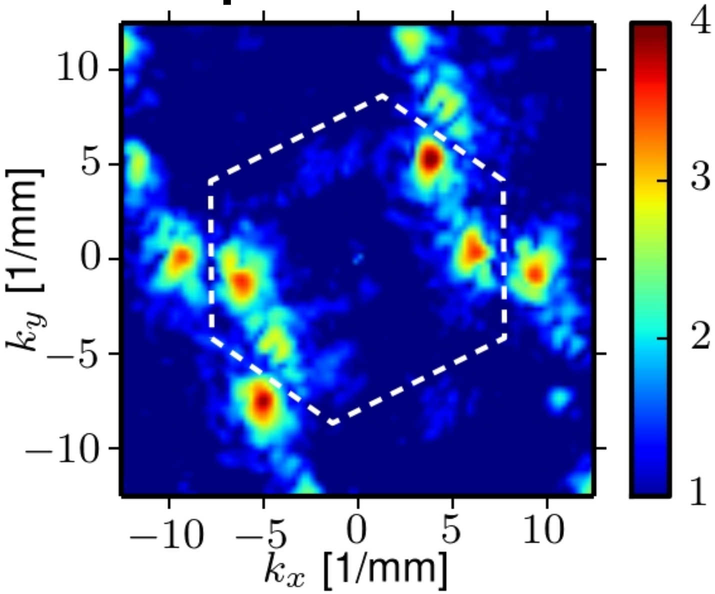




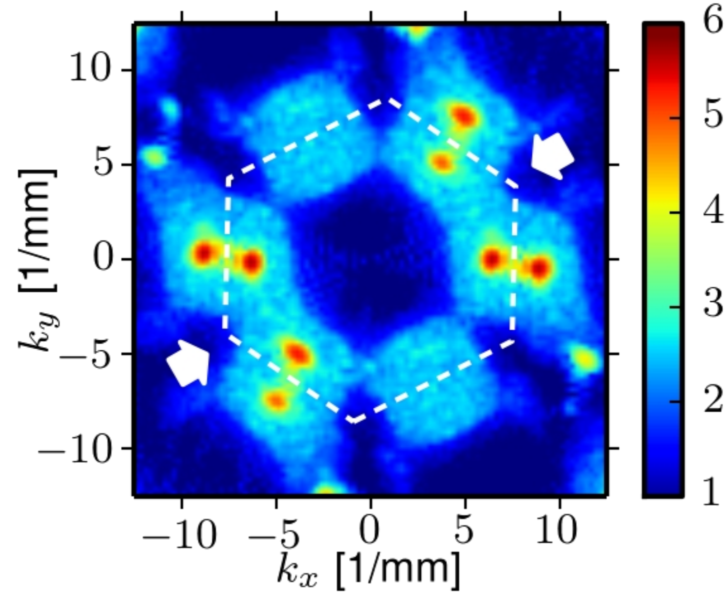
$\beta = 29.7 \pm 0.50$
$\epsilon = 0.36 \pm 0.03$

Velocity Fluctuation Spectra

Experiment

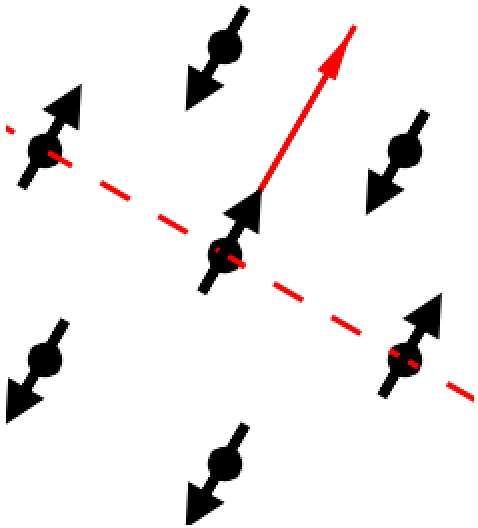


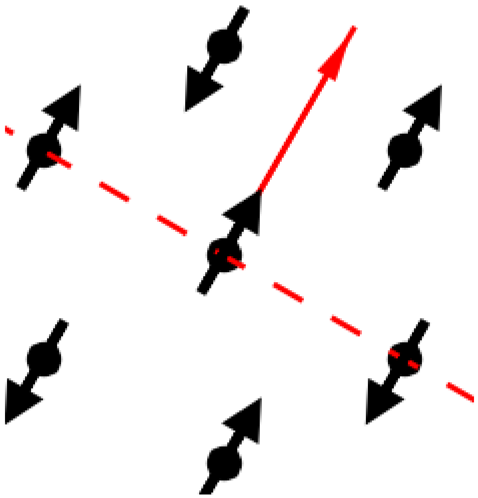
Simulation



$$\frac{\delta\Omega_{z,\mathrm{crit}}}{\Omega_{z,\mathrm{crit}}} \simeq 0.86\frac{\delta\Omega_c}{\Omega_c}$$

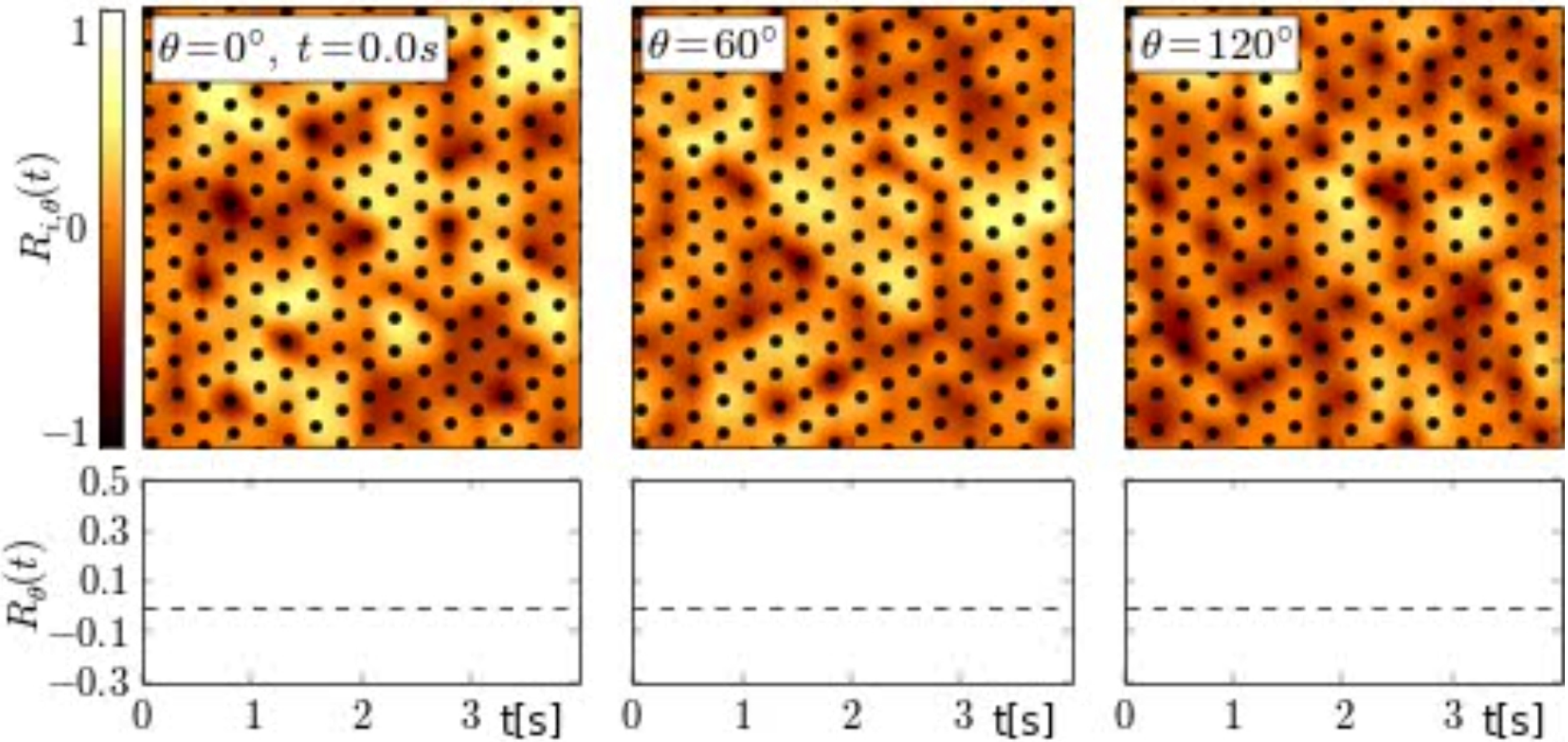
Order Parameter





$$R_{i,\theta}(t) = \frac{1}{\mathrm{nn}} \left(\sum_{j=1}^{\mathrm{nn}} \left[(-1)^{k_j} \cos(\phi_{j,\theta} - \phi_{i,\theta}) \right] \right)$$

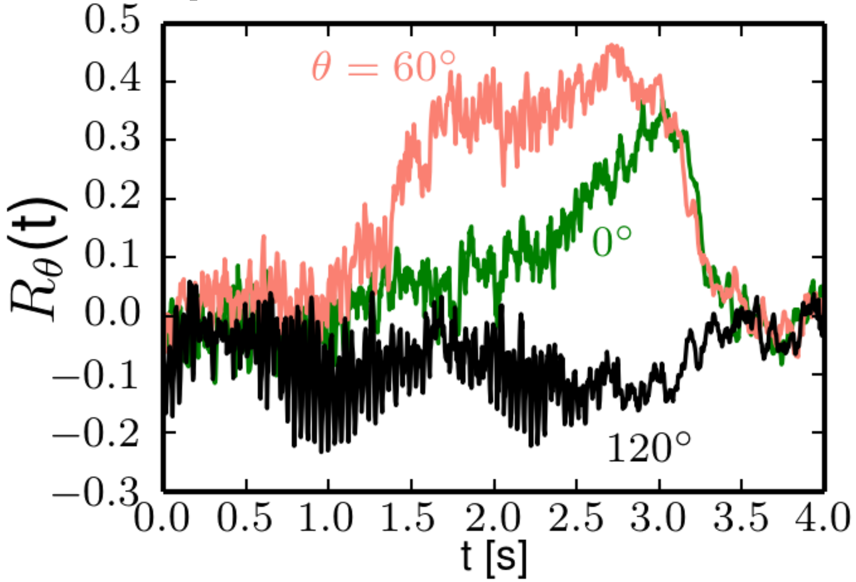
Order Parameter



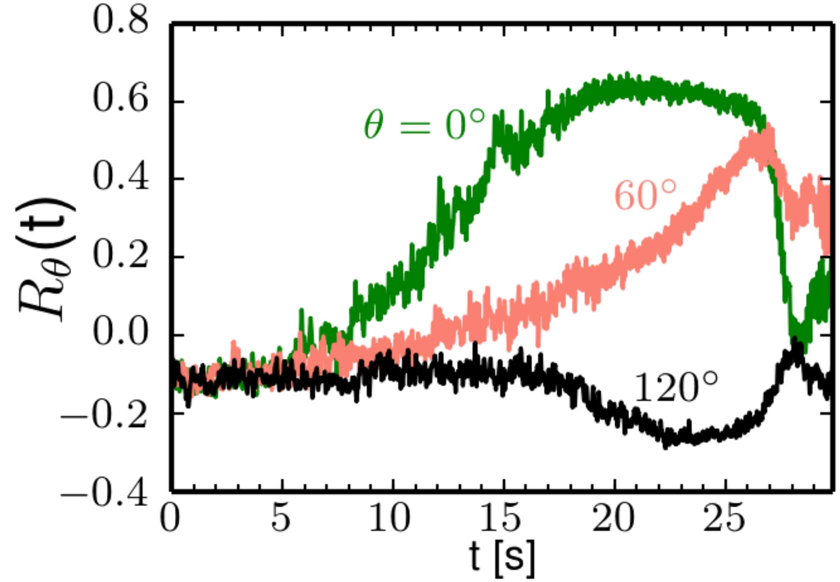
Order Parameter

Order Parameter

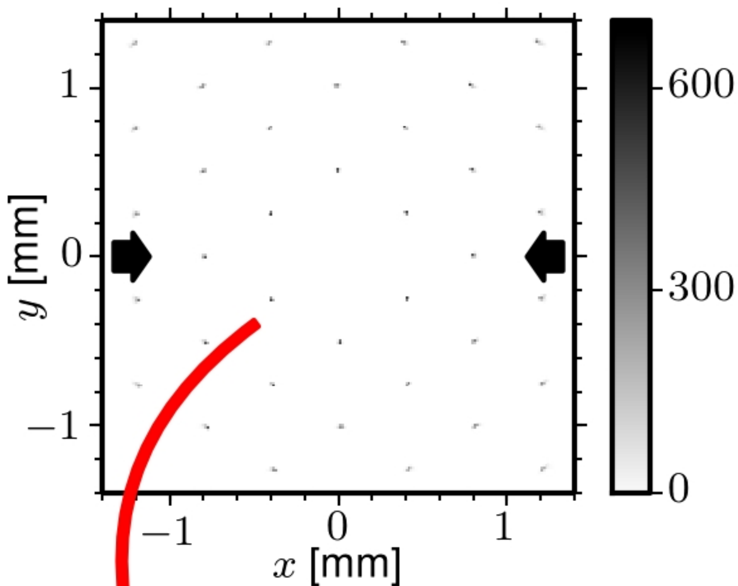
Experiment

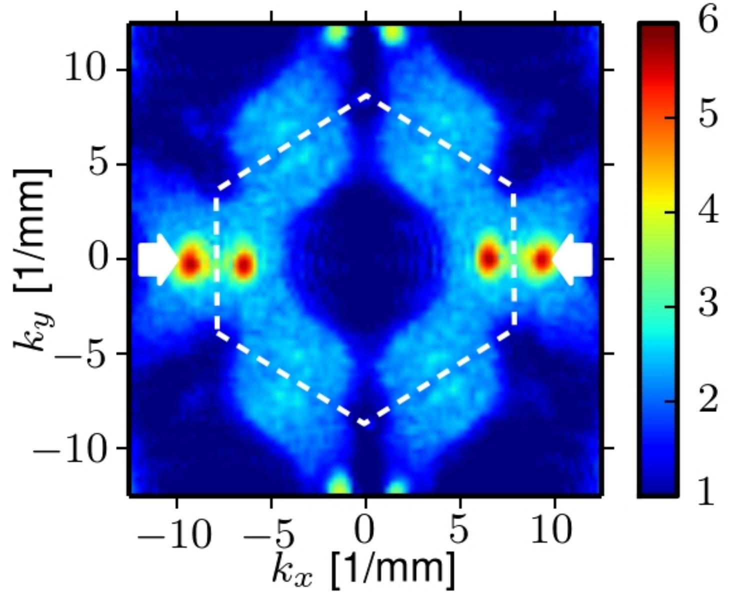


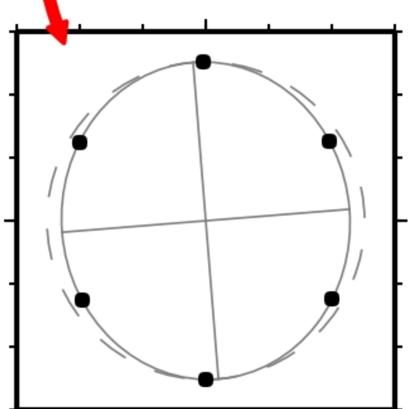
Simulation



Another Simulation

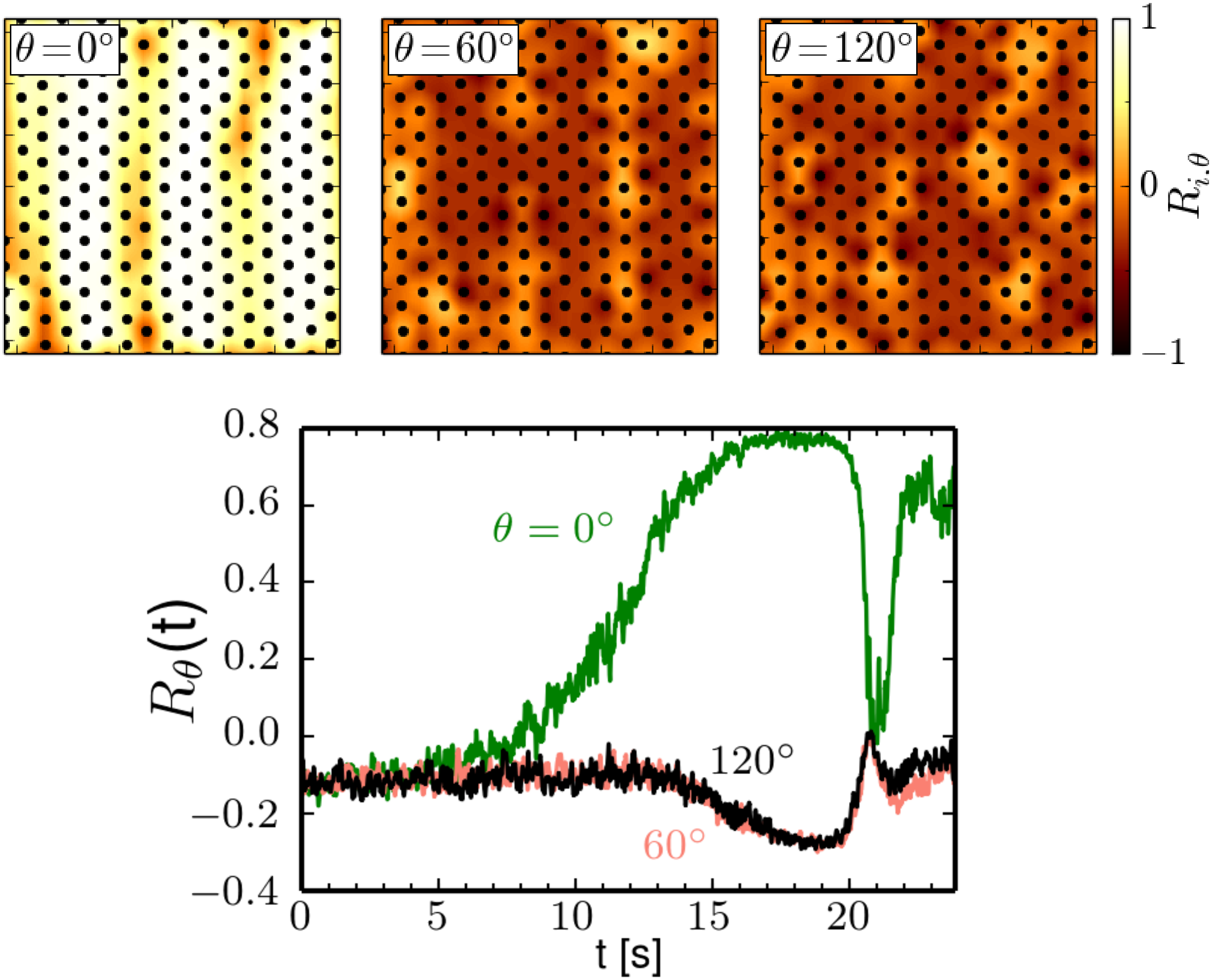






$\beta = 3.0 \pm 0.50$
$\epsilon = 0.42 \pm 0.03$

Another Simulation

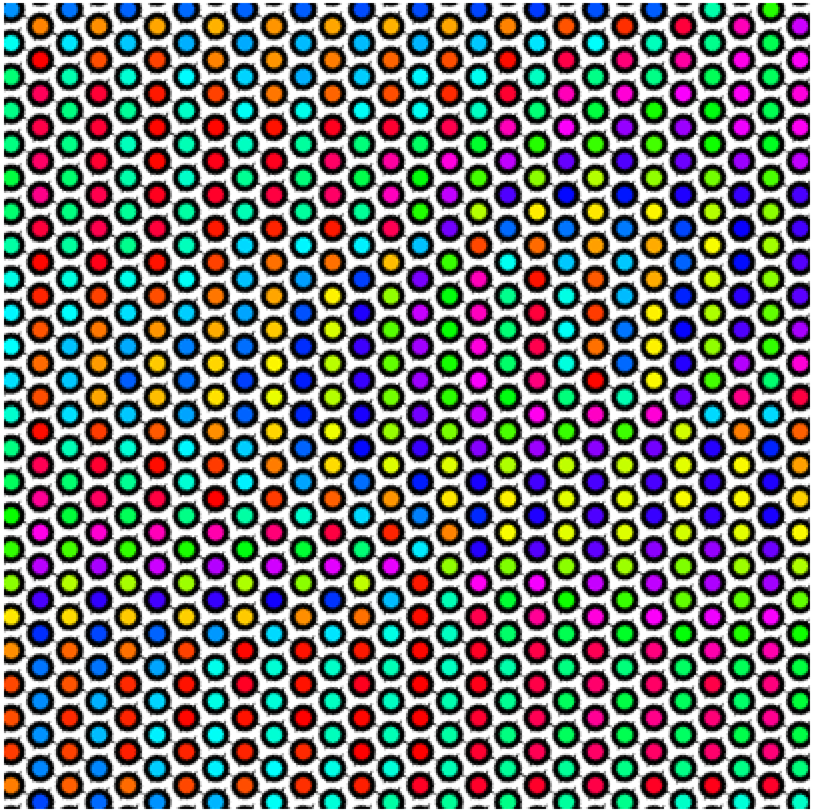


DLR

Outlook: Kuramoto-like description

$$\dot{\phi}_i = \omega_i + \sum_{j=1}^{\mathrm{nn}} K_j \sin(\phi_i - \phi_j)$$

Hong *et al*, PRE (2005)
Giver *et al*, PRE (2011)



Conclusion

- Horizontal compression of the crystal explains well the asymmetric triggering of MCI
- Competing patterns of synchronized motion

Simulation parameters

N = 16384

m = 6.1e-13 kg

Q = -19000e

f_z = 23 Hz, f_par = 0.156 Hz, f_perp = 0.137 Hz

nu = 1.26/s

lambda_d = 380e-6 m

q_tilde = 0.2

delta_tilde = 0.3